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Letter Report

Damping Characteristics of Metal Matrix Composites

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Prepared for:

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Quarterly Progress Report (#9)
(MCR-85-721)

1.0 Contract Number:
N00014-85-C-0857

2.0 Reporting Period:
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3.0 ONR Scientific Officer:
Dr. Steven G. Fishman

4.0 Work Performed At:
Martin Marietta Astronautics Group, Denver, CO 80201

5.0 Principal Investigator:
Mohan S. Misra

6.0 Project Title:
Damping Characteristics of Metal Matrix Composites

7.0 Description of Research:

7.1 Objectives of Present Research

Metal matrix composites (MMC) with enhanced material damping can be potential structural materials to improve significantly the stability, control and reliability of space structures. Objectives of this investigation are:

- Identify the mechanisms and sources of damping in continuous fiber-reinforced MMC (Gr/Al and Gr/Mg) using in situ characterization techniques.
- Determine the role of microstructural parameters (fiber volume, fiber orientation, interfiber spacing, grain size, precipitate morphology) in damping.
- Define the role of the fiber-matrix interface in damping.
- Develop high damping structural materials for space applications.

7.2 Summary of Work Accomplished During Previous Reporting Period

- Damping Measurements of Gr/Mg Composites

Damping Measurements at 10—50 Hz [Clamped-Free Flexure]

- Low frequency, low-to-intermediate strain amplitude damping tests in clamped-free flexure were conducted on both [0°] P55 Gr/Mg-0.6% Zr (Gr/K1A) and P55 Gr/Mg-1% Mn (Gr/M1A). As-cast Gr/K1A specimens were tested in a noncontact clamped-free flexure apparatus in vacuum over the strain amplitude range 15-170 $\mu\epsilon$ and frequencies ranging from 14-49 Hz. The results indicated that the damping capacity of Gr/K1SA remains nearly the same in the 20-50 Hz frequency range at a particular strain amplitude, i.e., $\psi \sim 1.2\%$ @ 15 $\mu\epsilon$ between 20-50 Hz. At frequencies less than 20 Hz the damping capacity values tend to increase as the specimen frequency approaches Zener relaxation frequency (~ 10 Hz). Damping measurements at different strain amplitudes indicated that ψ increases from 1% at 15 $\mu\epsilon$ to 1.8% at 170 $\mu\epsilon$. Based on these results, Gr/K1A starts to exhibit strain amplitude dependent damping response even at strain levels which are ~4% of failure (elastic) strain values.

Damping Measurements at 80 kHz (Piezoelectric Composite Oscillator Test Technique)

— As-cast Gr/Mg
- At $\varepsilon \leq 10^{-6}$ Gr/Mg exhibits strain amplitude independent damping response with $\psi = 0.9\%$
- At $\varepsilon > 10^{-6}$ the damping capacity of Gr/Mg increases with a strain amplitude maximum value 3% measured at $\varepsilon = 8x10^{-5}$

— After heat treatment @ 450°F for 6 hr
- The strain amplitude dependent response @ $\varepsilon > 10^{-6}$ was similar to the one observed for as-cast composites, and the maximum value of damping capacity increased to 4.2%.

— Strain amplitude dependence of damping characteristics for as-cast and heat treated Gr/M1A and Gr/K1A were analyzed in terms of Granato-Lucke (G-L) dislocation damping theory. An excellent fit was obtained for the G-L plot of the strain amplitude dependence of Gr/M1A and Gr/K1A. In all cases, the dislocation loop length calculated from the G-L analysis increased as a result of the heat treatments. As the position of the maxima in the strain amplitude dependent damping is predicted by G-L theory to occur at $\varepsilon_p = 2C_2$, the decrease in C_2 is consistent with the shift in peak position. Using a value of $L_N/L_C = 100$, an approximate value for the mobile dislocation density of 10^9 1/m^2 was obtained. This value for mobile dislocation density is in agreement with the 10^{14} values for total dislocation density obtained from TEM images.

Transmission Electron Microscopy

— These ion milled specimens of as-cast Gr/K1A were examined by TEM. The TEM images near the interface region indicated a good fiber-matrix bond, and the average matrix grain size appears to be less than the interfiber spacing (~ 3 µm). The interfacial bond is a result of a chemical reaction between the fiber coating (SiO_2) and Mg matrix, leading to the formation of Mg_2Si and MgO precipitates. TEM micrographs showing dislocation substructures near the interface were obtained by examining the specimens at various tilts. Near the interface, the dislocations are dense and tangled; and in the interfiber-matrix regions the dislocations are less dense and linear. Average estimated dislocation density in Gr/K1A is ~ 1.1 x 10^{14} 1/m^2.

7.3 Investigations in Progress

- Damping Behavior of Metal Matrix Composites

— Damping data were obtained for Gr/Mg composites in the intermediate frequency range as a function of temperature at low strain amplitudes ($< 10^{-7}$). As shown in Figure 1, a peak in damping was noted at 200K (-73°C), which can be attributed to a phase transformation in graphite from rhombohedral to hcp structure. At temperatures above 373°K, the increase in damping can be attributed to the operative mechanisms operative in the matrix alloy.

— Flexural and extensional damping capacity of as-cast and heat treated Gr/K1A were also measured at $\varepsilon < 10^{-6}$ by using the test apparatus (Figure 2 and 3) available at University of Idaho, Moscow, Idaho. These results (Table I) indicate that flexural damping capacity 1.5% @ 80 Hz, is quite consistent with the values previously obtained at Martin Marietta.

— The extensional damping capacity measurements were performed at ~ 2kHz. For as-cast specimens, the enhanced extensional damping capacity (Table II) ~ 10% @ 1977 Hz could be attributed to a characteristic grain size or damage length plays. Therefore, microstructural analysis is in progress to identify the source of energy dissipation. The flexural and extensional damping capacity measurements for heat treated specimens are listed in Table III and IV, respectively. Test results show that flexural

damping values are nearly identical to the values obtained for as-cast specimens, and @ ~ 2065 Hz is 5.6%. Based on these results, it appears that the microstructural modifications introduced by heat treatment @ 800°F for 16 hours did not enhance composite damping.

— Another method to enhance the damping of graphite-reinforced metal matrix composites is to increase vibrational energy dissipation within the fibers themselves. For example, moduli-weighted rule of mixtures provides an estimate of baseline damping capacity value at very low strain amplitudes where the composite exhibits nearly anelastic response.

i.e., $\psi_{11} = V_f(E_f/E_{11})\psi_f + V_m(E_m/E_{11})\psi_m$

During cyclic deformation of the composite most of the strain energy is stored in high modulus fibers, and if their damping capacity can be improved it would provide an effective approach of enhancing material damping. Preliminary calculations show that the damping contribution from the fiber and matrix are equivalent for $\psi_f = 2\%$ and $\psi_m = 30\%$. Data available from SPARTA, Inc. shown in Figure 4 indicates that intercalated fibers do exhibit high damping. Consequently, incorporating these intercalated Gr fibers with Mg matrix could yield potentially high damping composite.

P100 Gr fibers have been Bromide intercalated. Because intercalants have a tendency to escape the fibers when exposed to temperatures above 350°F, fabricated fibers were plated with electroless nickel, and then dipped in molten Mg bath to prepare precursor wires. Damping tests of nickel plated fibers and Gr/Mg precursor wires are in progress to determine if enhanced damping due to intercalant is retained during composite fabrication.

— Torsional pendulum tests are being conducted to determine the temperature dependence of the damping. These tests, in conjunction with the strain amplitude tests conducted earlier, will identify the contribution to strain amplitude independent damping from dislocation motion, as well as quantifying other anelastic damping mechanisms operative at low strain amplitudes.

- In Situ Characterization

<u>Acoustic Emission</u>

— Wire specimen geometry tests are in progress to determine the correlation to low and intermediate stress level acoustic emission and microstructural changes. Gr/M1A and Gr/K1A precursor wires have been fabricated. Tensile tests will be interrupted at 20%, 30%, 40%, 60%, 80%, and 100% of failure load. Where AE source location indicates a localized event source, microstructural investigations will be conducted, particularly at the fiber-matrix interface. These data will be correlated with AE analysis to provide an understanding of the fiber-matrix interfacial phenomenon in Gr/ Mg composites.

— Experiments to determine the effects of the 800°F, 8 hour treatment upon the AE from the fiber-matrix interface are in progress on Gr/Mg-1% Mn specimens.

7.4 Presentations

- SDIO/IST Advanced Composites Program Review at Woods Hole, MA, June 7, 1987.
- "Damping Mechanisms in Continuous Gr/Mg Composites," presented at the American Ceramics Society Meeting, Cocoa Beach, FL, January 20-22, 1988.
- "Internal Friction in Cast Graphite-Magnesium Composites," presented at the Materials Research Society meeting in Reno, Nevada, April 5-8, 1988.

7.6 Technical Reports

- None

7.7 Publications

- None

7.8 Participants

Name	Task
Material Concepts, Inc, Columbus, OH.	Flat cast composite panels
University of Illinois	TEM with deformation stage
University of Texas A&M, College Station, TX	Damping measurements
University of Denver, Denver, CO	Damping measurements In situ characterization
University of Wisconsin-Madison, Madison WI	In situ characterization

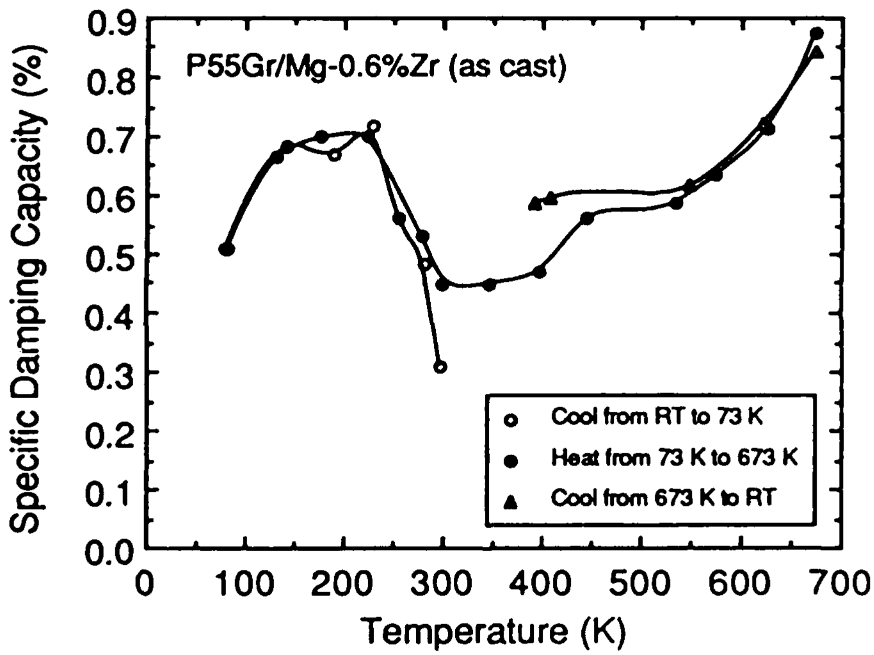

Figure 1
Damping Characteristics of As-Cast Gr/K1A as a Function of Temperature Indicating Contribution from Rhombohedral to HCP Phase Transition in Graphite at 200 K.

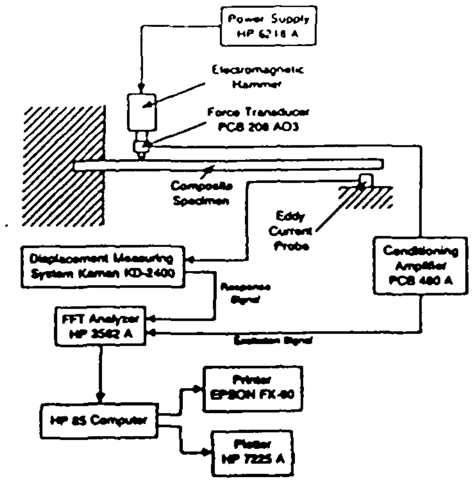

Figure 2
Flexural Damping Apparatus Used to Obtain Measurements Given in Tables I and III.

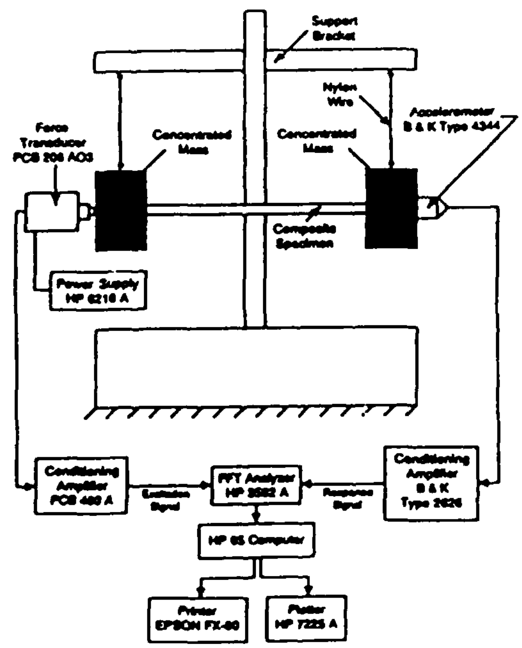

Figure 3
Extensional Damping Apparatus Used to Obtain Measurements Given in Tables II and IV.

Table I - Experimental Results for Gr/K1A Mg [0°] Under Flexural Vibrations

Specimen Length (inch)	Frequency (Hz)	Ψ (%)			Storage Modulus (10^6 psi)		
		U	M	L	U	M	L
7	60.358	2.52	2.29	2.06	20.670	20.660	20.660
6	82.996	1.51	1.48	1.46	21.090	21.090	21.090
5	118.907	2.27	2.25	2.23	20.890	20.880	22.870

Specimen density = 0.072 lb/in^3

Temperature = 70°F

Humidity = 60%

U, M, L = Data scatter representing upper limit, mean value and lower limits of the experimental results

Table II - Experimental Results for Gr/K1A Mg [0°] Under Extensional Vibrations

Frequency (Hz)	Ψ (%)			Storage Modulus (10^6 psi)		
	U	M	L	U	M	L
1676.006	4.84	4.79	4.75	21.370	21.290	21.270
1976.321	10.5	10.07	9.66	21.350	21.340	21.330
2881.760	3.19	3.05	2.9	25.320	25.300	25.290

Specimen Length = 6.5"

Table III - Experimental Results for Gr/K1A Mg Heat Treated [0°] Under Flexural Vibrations

Specimen Length (inch)	Frequency (Hz)	Ψ (%)			Storage Modulus (10^6 psi)		
		U	M	L	U	M	L
7	58.336	2.38	2.38	2.38	19.040	19.040	19.040
6	81.594	2.06	2.06	2.06	20.100	20.100	20.100
5	115.913	2.46	2.25	2.23	19.570	19.560	19.560

Specimen density = 0.071 lb/in^3

Temperature = 70°F

Humidity = 60%

U, M, L = Data scatter representing upper limit, mean value and lower limits of the experimental results

Table IV - Experimental Results for Gr/K1A Mg Heat Treated [0°] Under Extensional Vibrations

Frequency (Hz)	Ψ (%)			Storage Modulus (10^6 psi)		
	U	M	L	U	M	L
1731.173	2.26	2.15	2.04	22.720	22.710	22.700
2065.039	5.6	5.46	5.322	23.330	23.300	23.270
2739.542	4.755	4.71	4.67	22.870	22.870	22.860

Specimen Length = 6.5"

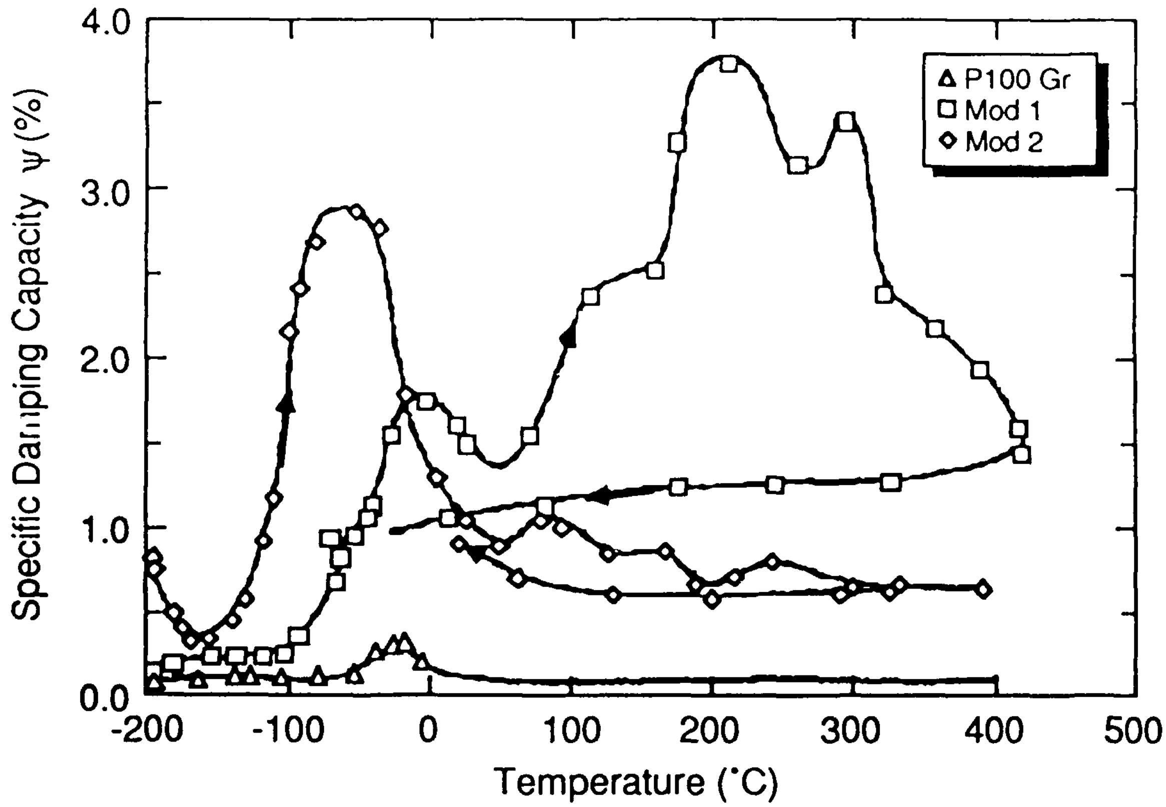

Figure 4
Damping Behavior of Graphite Fibers Indicating Significant Increase in Damping as a Result of Intercalation (Courtesy of SPARTA).